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ABSTRACT

Visual knowledge is an enormously important part of our total knowledge. The psychological study of learning and knowledge has focused almost exclusively on verbal materials. Today, the advance of technology is making the use of visual communication increasingly feasible and popular. However, this enthusiasm involves the illusion that visual communication is transparent and overcomes problems of comprehension. The effort to understand how visual media can be used effectively in educational communication returns to the most basic and general questions about how visual information is coded and processed. Everything that is learned in the history of research on vision is relevant to the understanding of effective visual representation. Some of the gaps in knowledge are made more evident when this problem is analyzed. As yet, for example, there is not much to say about the kinds of visual comparison processes or perceptions of relationships that are involved in using graphs to answer questions about the information they represent. A kind of deep unity is emerging in what had been some very disparate areas of investigation--abstract pattern perception, graph reading, imagery, spatial ability--a unity that arises from the common involvement of a perceptual system that evolved to serve particular functions. Hypothetical though it may be, this source of unity can guide researchers in more fruitful and systematic investigations than has been seen in the past. Visual knowledge builds on a very powerful perceptual apparatus, but it is knowledge nevertheless, and it continues to grow and develop throughout life. (Twenty-five references and 18 photocopies of slides are attached.) (RAE)

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VISUAL KNOWLEDGE

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Office of Naval Research

Paper presented at AERA (Invited Address: Div. C)

April, 1987, Washington, D.C.

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Introduction

(The paper began with the showing of about 10 miscellaneous color slides, mostly with scenic content. No narration.)

I have shown these slides as a reminder of the enormous importance of visual experience in our total fund of knowledge. Most of them result in very rapid comprehension of the nature of the scene; some may have been recognizable as pictures of a particular place known to you -- the cherry blossoms you just missed seeing, for example.

Even if I went on showing slides like this for hours, you would have an excellent ability to recognize those you had and had not seen.

Visual knowledge is an enormously important part of our total knowledge. Yet, the psychological study of learning and knowledge has focused almost exclusively on verbal

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materials. Today, however, the advance of technology is making the use of visual communication increasingly feasible and popular. Often this enthusiasm involves the illusion that visual communication is transparent and overcomes problems of comprehension. I would argue that our scientific understanding of visual knowledge is so underdeveloped that we are rarely able to determine what the quality of understanding is.

There are many topics that might be discussed under the general rubric of visual knowledge:

(many of these were illustrated with slides)

Diagrams to explain mechanical devices

Body language in human interaction

Facial expressions

Chemical diagrams

Book illustrations

Symbol systems (eg international traffic signs) -- computer icons being a current variant

Spatial ability

Children's drawings and maps

Composition in art

Machine vision

Abstract pattern perception

Cognitive maps

Mental imagery

Picture memory

Many types of diagrams

electric circuit diagrams

blueprints

ancestral trees

But I have selected only three for discussion:

Basic Objects

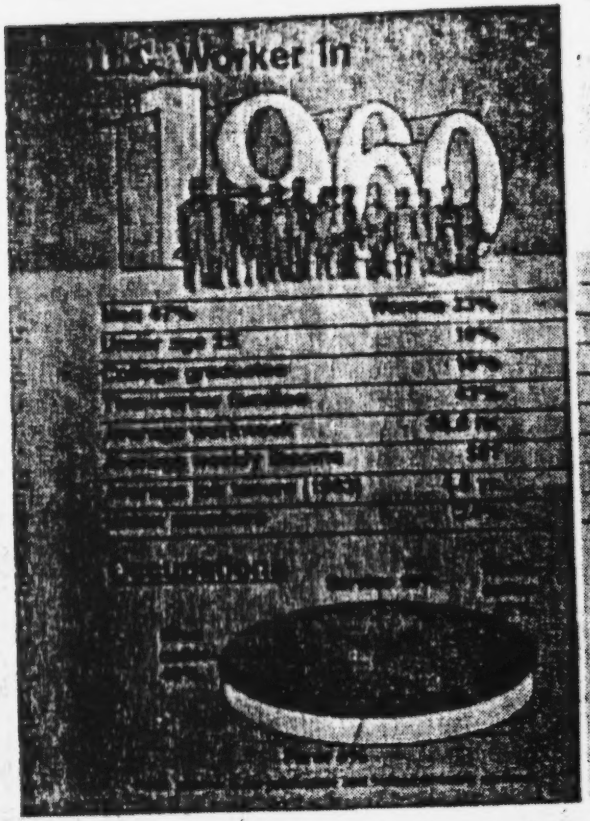
Graphs and Charts

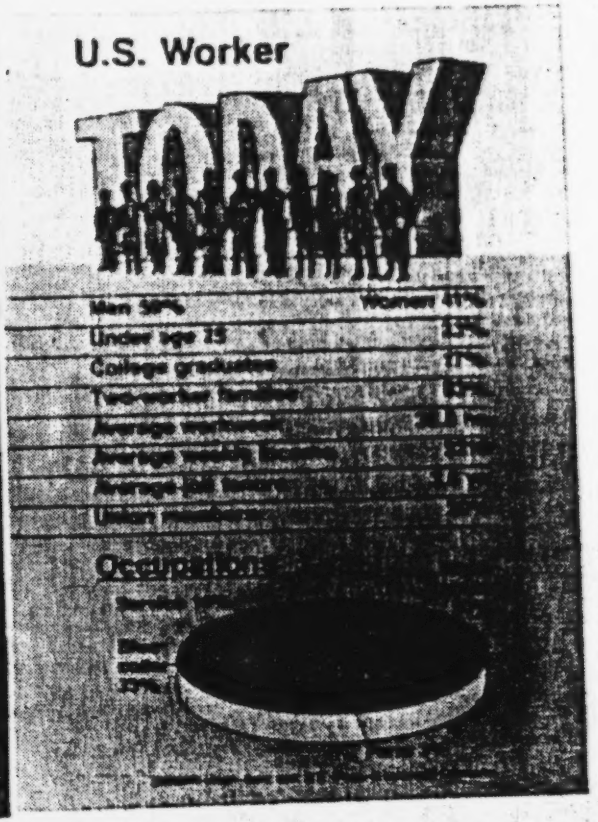
The Use of Visual Representations in Problem Solving

Basic Objects

Over 10 years ago, George Miller and Phillip Johnson-Laird lamented the neglect -- by psychology, linguistics, and even philosophy -- of the fact that language can apply to the non-linguistic world. Of the fact that we talk about perceived experiences of the external world. Mostly, psychologists have studied relations among words. Of course, relations among words are important, too. There are many abstract concepts which are best defined within an internal symbolic world. But there are at least some fundamental concepts which tie words, meaning, and language to the perceived world.

How much of what we know about familiar things is VISUAL information?


Worker in
1960


U.S. Worker
TODAY
Under age 25
College graduates
Occupations

68

5

5-A

e "Innovation Recession"

worry about the U.S. economy: the decline in R and D

...the devaluation of the dollar ...be the most dramatic measure ...S.'s reduced thrust in world com... another event may ultimately have ...r impact on the nation's economic ...h. It is the shocking decline of good ...ake ingenuity, otherwise known ...rch and development.

...U.S. has always prided itself on ...be world's undisputed leader in ...ical innovation. Since World ...Green demand for aircraft, com... automated tools and other prod... American labs and workshops ...e relied on to provide a fat sur... the nation's balance of trade. No... Though the U.S. still retains an ...lead in total amounts spent on R ...and in numbers of new inventions, ...if economic rivals are expanding ...search efforts at much faster rates, ...mergence is becoming dramatic... year this year, because the U.S. no... commands such a high share of ...the high-technology market, it no... can offset its large imports of low... ...ow items such as shoes and cloth... ...As a result, in 1978 the country will ...substantially more manufactured ...than it will export. The deficit for ...e half of 1978 was $11.9 billion ...will do more damage to the trade ...e this year than anything but the ...ft in oil that the U.S. will im... ...By contrast, West Germany and ...are expected to run surpluses in ...factured goods of $49 billion and $6... ...respectively.

...ording to the National Science ...undation, in the years 1961 ...o 1968 the U.S. introduced 44 ma... ...chnological innovations. West Ger... ...Japan, Britain and France had ...ver only 20. But now foreign com... ...es are bringing out as many new ...cts and processes as the U.S. ...

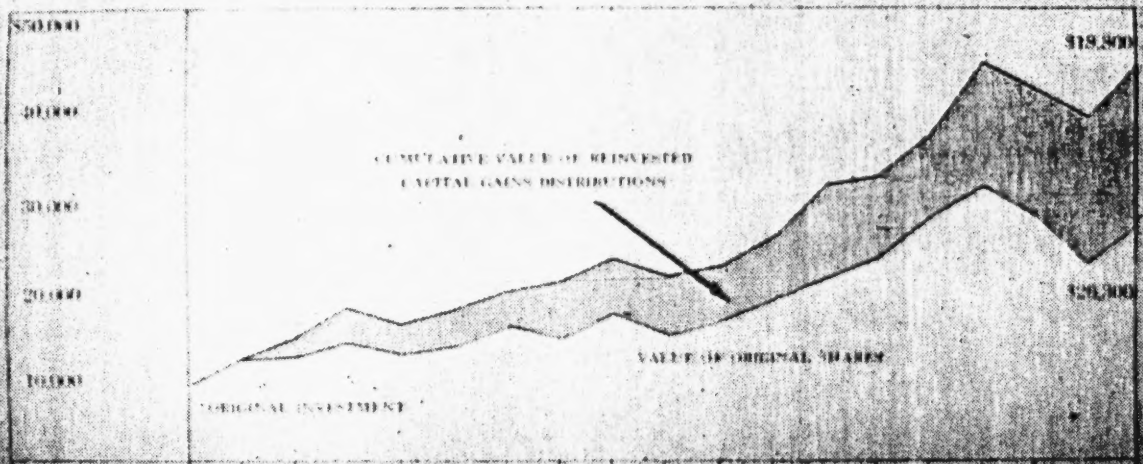
...In the category of new patents, a ...measure of R and D vitality, Ameri... ...inventors were granted 45,633 pat... ...by major trading partners in 1960, ...the U.S. gave only 9,467 to those ...rivals that year. By 1976, however, ...so-called patent balance had shifted ...fully. The number of U.S. inventors' ...ted patents abroad dropped by more ...than 50%, to 11,181, while the number of ...gners earning U.S. patents had al... ...doubled, to 19,738. Says Frank Press, ...chief White House science adviser: "It ...s trends that are important, and the ...ntage increases in some countries ...rowing faster than here."

...Why did the trends begin to shift? Ar... ...M. Bueche, senior vice president for ...ch and D at General Electric, which ran... ...as the most research-oriented of big ...companies (862 patents won last ...), is concerned about a change in the ...ican character. Says he: "We've ...gone from an expansive, gung-ho attitude to a defensive, 'What's in it for me?' attitude. Faced with a challenge, Americans are now more likely to say, 'Let someone else do it.' Among factors behind the U.S.'s 'innovation recession':

THE MONEY DRAUGHT. Since the heady Sputnik days of 1964, when public and private spending on R and D reached a peak of 3% of the gross national product, such spending has slipped to just 2.1% of GNP. That is appreciably lower than West Germany's 2.4% and uncomfortably close to Japan's 1.9% and even France's 1.8%. Furthermore, while foreign countries spend very little on military research, the U.S. dedicates almost 40% of its R and D expenditures to defense related projects. At the same time, federal spending on basic research has fallen in constant dollars from $2.6 bil-

discontinuit + truncation

Some milestones in American ... co television sets at Apollo 8's ...



Year	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Dividends Received	$380	420	470	490	490	450	440	440	490	510	530	560	580	600	620	640	660	710
Reinvested Capital Gains Distributions	$390	550	630	720	870	870	790	790	290	680	860	1100	1510	1530	1560	1100	1300	1300

[illegible] of reinvesting capital gains
[illegible] earned on a $10,000 investment

it among the top 100 firms on the FORTUNE 500 index even if it had no oil.

Diversification should keep the Seven formidable for the foreseeable future, though their individual fortunes vary.

EXXON, the world's largest energy concern, suffered an 8% drop in profit last year, to $2.4 billion, but only because the weakness of the dollar increased the number of greenbacks that will be needed to pay off its foreign debts. In the first half of this year, however, its net increased 13%, to $1.4 billion, and the quarterly dividend was raised 10¢ a share, to 85¢. Exxon is a price example of strength begetting strength. It has bid top dollar on the choicest drilling leases around the world and has participated in all the major new finds. It has a 25% interest in Alaska's Prudhoe Bay fields and a major stake in the North Sea.

To guard against the day when the oil runs out, Exxon since 1970 has acquired coal reserves of more than a billion tons and now operates several mines. It is also pushing some ventures far removed from oil. For example, early this year it introduced Qyx, a computer-programmed typewriter designed to undersell word processing IBM and Xerox machines. One indication of Exxon's strength: it plans a staggering $24 billion in capital expenditures over the next four years, to be financed just about entirely out of its own cash, with little if any borrowing.

SHELL, No. 2 in oil and the biggest business of any kind based outside the U.S., increased profits about 9% last year, to $2.3 billion—almost as much as Exxon earned on far greater sales. Of all the Sisters, Shell seems best suited to benefit from the trend toward getting a larger share of profit from refining and marketing. The firm has long concentrated on those areas, to the point that outside the U.S. it buys around 80% of its crude from other companies. Says Shell's European coordinator Jan Chouffer: "Adding value to bought crude is the name of our game."

To that end, Shell has gone farther than any of the Sisters toward "whitening" its production—that is, squeezing more high-profit gasoline, kerosene and other light fuels out of each barrel of crude. It is also profiting handsomely from its 30% interest in the large natural-gas fields in The Netherlands.

MOBIL seems to be doing just about everything right. Its profits rose 7.5% last year, to just over $1 billion, and another 16% in the first half of 1978. Traditionally strong in marketing, it has been leading the swing to self-service gas stations in both the U.S. and Europe. Indeed, it was the only Sister to earn a profit last year in the fiercely competitive West German market.

In addition, Mobil has strengthened its position as an oil and gas producer with major interests in the North Sea and luck in the Gulf of Mexico. Last year it sank 29 wildcat wells there and struck oil in 14, a feat about equal to a baseball player hitting .422. Mobil has also made important nonenergy investments. It is the Seven in 1976 it completed a [illegible] over-all Marcor parent Montgomery Ward of America and Montgomery Ward last year these subsidiaries earned $[illegible] lion, or 17.5% of Mobil's profits.

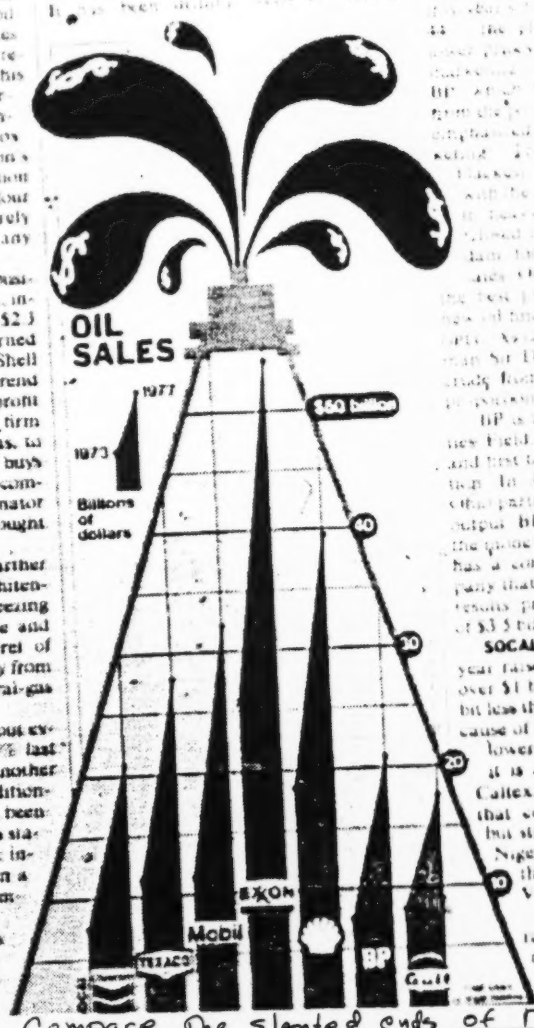
TEXACO is currently a [illegible] 1977 its profits rose [illegible] but in the first half of [illegible] plunged 2[illegible]. Texaco has stayed far away from [illegible] oilfields, where competition is sharpest and returns on investment are much of its money into [illegible] new finds are [illegible] of being lifted. Instead, it has concentrated on the [illegible] est North Sea [illegible] traditional [illegible] promising [illegible] Indonesia [illegible]

BRITISH PETROLEUM

BP is the main developer of the new field one richest in the North Sea and first to come into large-scale production. In Alaska a BP-Standard Oil of [illegible] partnership controls Sohio, a major producer. BP took Sohio stake in 1969 as the price it invested in Alaska and now has a controlling 51.2 share of the company that is a giant in its own right, with [illegible] profit of $181 million on revenues of $3.5 billion.

SOCAL, one of the western Sisters, last year raised profits about 15%, to nearly over $1 billion. This year its net figures but less than 3% in the first half partly because of higher exploration expenses and lower earnings from Indonesia, where it is a 50-50 partner with Texaco. In Libya, Caltex Socal pulled out of Libya after that country nationalized its assets, but still gets crude from Bahrain, Nigeria, Saudi Arabia (where it was the first to discover oil) and Venezuela.

Domestically it increased exploration outlays 44% last year, to $[illegible] million, and found oil in Alaska, California, Wyoming and the Gulf of Mexico. Socal has also begun



Compare the slanted ends of the bars

[illegible] evidence of substantial learning over [illegible] Performance on the Letter and [illegible] for both the Letter-Word and Word-Letter [illegible] over orders. As can be seen from [illegible] was a steady increase over trials in the percentage correct, primarily due to a reduction in omissions. Of [illegible] correct on the fourth trial, 88 percent were also correct [illegible] with an overall percentage correct on the fifth [illegible] In other words, if the Letter list subjects retained [illegible] learned items from one trial to the next, and added to this store of [illegible] items on each trial. The pattern of results for the Word list, on the other hand, was similar to that previously described for the *Alphabet* and *Classify* tests. None of the performance measures changed to any noticeable degree over the five trials.

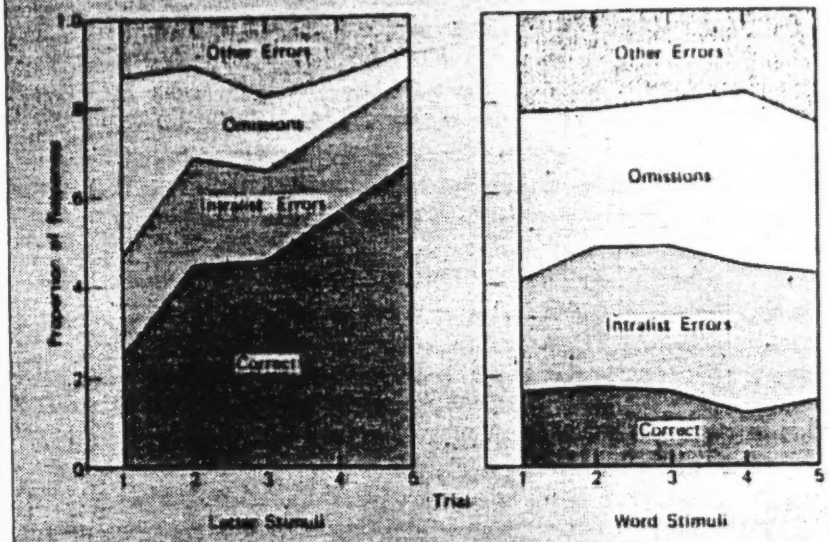


Figure 6.2 Letter-word test responses to letter and word lists over trials.

Summary. The kindergartners tested found it extremely difficult to form associations between the unfamiliar abstract stimulus-response pairs used in this portion of the BST package. The only exception was the Letter list of the *Letter-Word* test. The major distinctions between this latter list and the others were length (three pairs) and the elemental nature of the stimuli and responses (/m/, /n/, and /o/). The effect of list length on paired-associate learning is well known, but in the BST package the variation in length was relatively slight (three pairs in the *Letter* list to six pairs in the *Alphabet* list). Except for the Letter

George Miller likes to test the quality of dictionaries by looking at the definition of the word fox. He quotes this from a children's dictionary: "a wild carnivorous mammal." Not very informative. My unabridged dictionary does somewhat better: "any of a group of small, wild, flesh-eating animals of the dog family, with bushy tails and, commonly, reddish-brown fur." A picture of sorts is provided, too. But doesn't a slide like this one contain much more of the information we have about foxes?

(here a color slide of foxes was shown)

The point becomes more obvious when we consider an unfamiliar animal. Consider the meerkat. A meerkat is not a mere domestic pet. My dictionary says that it is "an ichneumonlike animal." That didn't even make contact with my semantic net. An ichneumon is defined as a "small weaselike animal." Weasels, in turn, are defined as "any of a world-wide group of cunning, agile, flesh-eating mammals with a long, slender body, short legs, and a long, bushy tail." Still, I'm sure that this slide gives you a much better sense of what a meerkat is, probably quite different from what you had in mind.

(here a color slide of meerkats was shown)

Another way we can learn about the meaning of words is to encounter them in context. Consider the bonobo and this sentence: "Chimpanzees (along with bonobos and gorillas) are our closest living relatives." That sentence tells you

a lot about bonobos, but I would be willing to bet that what you had in mind for your closest living relative isn't nearly as rich as this:

(a slide of a bonobo was shown)

How much of the content of these natural concepts is dependent upon visual information? Subjectively, it seems that quite a bit is.

At about the same time as Miller and Johnson-Laird, Eleanor Rosch made a significant foray into this problem with her investigations of natural perceptual categories and basic objects. She characterized the level of basic object concepts as having exemplars with similar, recognizable shapes of which one can form a single visual image. Although those of us who specialize in pattern perception, where the recognition of such objects has always been considered a major, classic problem, do have some difficulty with this claim. She presented evidence that basic object terms are acquired first, verified as correct labels more rapidly, provide the preferred level of label as contrasted to subordinate or superordinate terms, etc.

A recent article by Huttenlocher and Smiley confirms the early acquisition of these object categories and their apparent independence of other terms that some might consider to be defining attributes of particular objects.

But, generally, the study of language and semantics

continues as an enterprise disconnected from the study of the information that perception provides.

Why?

I believe that the key can also be found in a statement made by Miller and Johnson-Laird: "We will try to imagine what the output of a perceptual theory might be if we had it." That is, they postualated computational identification procedures to serve as the link between perception and language. Few are so brave in building major edifices upon air.

We still do not have that perceptual theory for ooject identification, but perhaps we are about ready to get one. There is a convergence of psychological theory with computational research in machine vision. The effort to get machines to do what people do so easily clarifies the nature of the theoretical problem. There is an emerging view that objects are perceptually built up of parts that themselves can be characterized by a relatively limited vocabulary of forms -- phonemes of form, one might say.

Tversky and Hemenway pursued the basic object idea, producing evidence that "parts" are critical in defining the basic level. Subordinates to the basic level share parts of the same type; different basic objects are differentiated by having different parts.

Hoffman and Richards have shown how a visual configuration is partitioned into parts at concave

discontinuities.

Several (many no doubt) proposals have been made concerning the set of primitives that should be used to describe these parts.

David Marr, the central figure in the rise of modern computational theories of vision, proposed the use of cylinders to describe parts. But it is obvious that you can't construct things that look like real objects using only cylinders. (a slide was shown of Marr's cylinder representation)

Biederman has made a more specific analogy to the idea of phonemes in speech, suggesting that a small set of distinctive visual features can be used to define a class of forms. The distinctive features include the contrasts between a) curved and straight sides, b) parallel and coterminating sides, c) symmetrical and assymetrical forms and so on.

(a slide was shown of Biederman's forms)

Biederman further suggests that these properties are pretty much invariant with viewpoint, solving that aspect of the object recognition problem. His proposal is very interesting, but I don't think that he yet has strong experimental evidence that the theory is adequate.

On the Artificial Intelligence side of these investigations, Alex Pentland has a somewhat similar proposal using forms he calls superquadratics. By

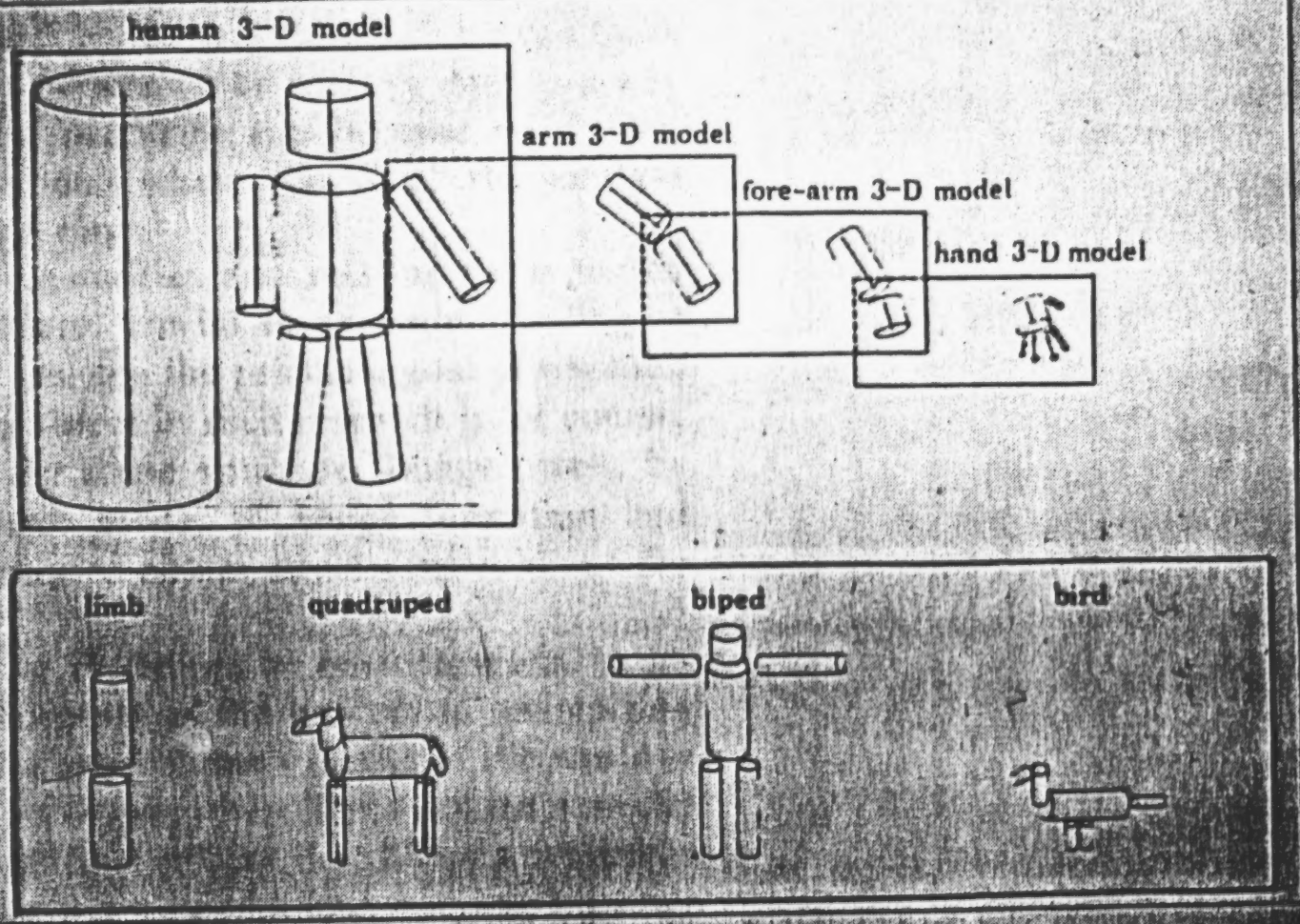
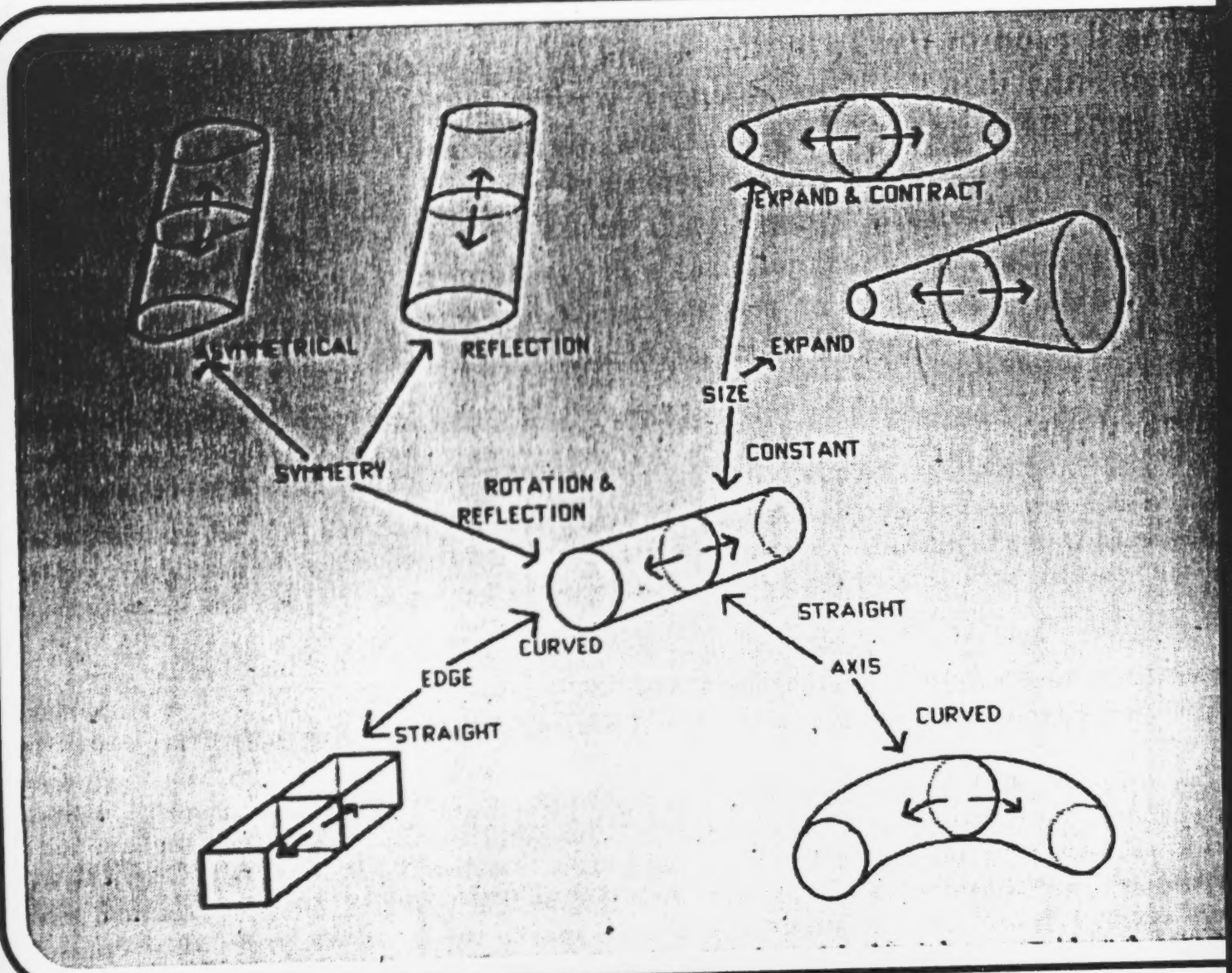
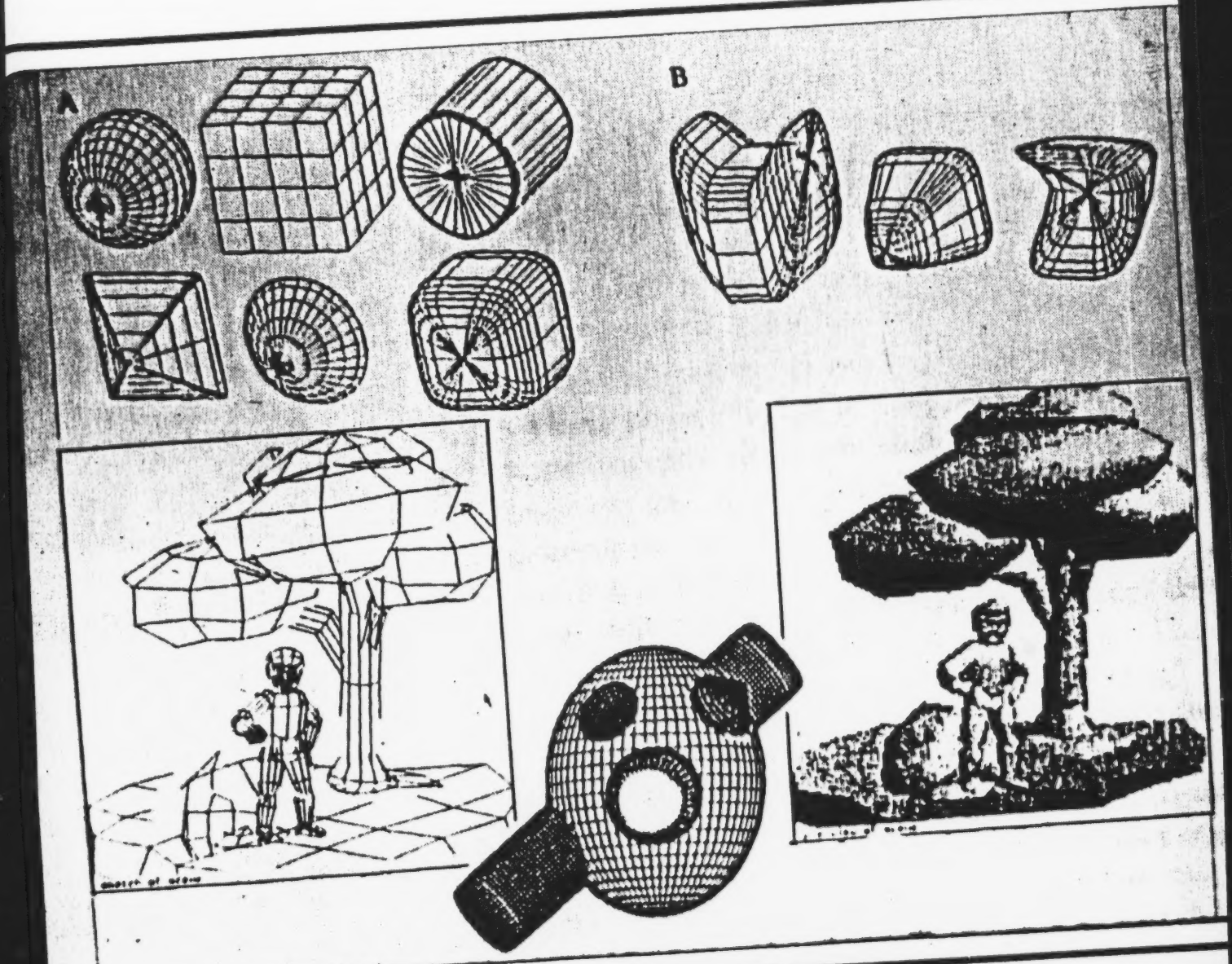


FIG. 2. Marr and Nishihara's scheme for the description of biological form.


EXPAND & CONTRACT
EXPAND
SIZE
CONSTANT
ASYMMETRICAL
REFLECTION
SYMMETRY
ROTATION &
REFLECTION
STRAIGHT
AXIS
CURVED
CURVED
EDGE
STRAIGHT

Pentland



sythesizing forms, he is able to show that these (with the addition of texture, etc.) can provide rather realistic looking objects. But of course he has no evidence for the psychological reality of his set of primitives.

(a slide was shown illustrating Pentland's forms)

The problem of stimulus generation has always been a major obstacle in pursuing research into the more complex aspects of visual processing. The kinds of computation resources represented by Pentland's work make it possible to investigate ideas such as Biederman's, to test their psychological validity.

Then, one can look at how memory for shapes and objects is organized and indexed -- begin to explore the realm of our visual knowledge. When, for example, George Miller uses a videodisk to aid in the teaching of word meanings, what is the nature of the visual information provided? Today, we really do not know. And objects are only the beginning -- scenes, motions, and events need explication as well.

Graphs and Charts

Now, I turn to the visual medium for conveying information that has probably received more serious psychological investigation than any other -- graphs and charts. Despite that investigation, we still have a long way to go in understanding what makes a good, effective graph and in being able to produce them routinely. Both in what has been learned, and in what is still problematic, there are lessons for those who want to exploit the graphic potential of new computer technology.

The Social Graphics Bibliography, an annotated bibliography, documents most of this vast research literature -- which is very fragmentary and unsatisfying because it is not based on any systematic, thorough-going analysis of graphic representation.

Many would agree that the best available treatment of graphic representation is the book by Bertin, who headed the French cartographic laboratory when he wrote it. The reason it is good is that Bertin has a deep insight into the fundamental nature of graphic representation. He understands that it is a mapping (in the general, abstract sense that mathematicians mean mapping) between the information that one is talking about (with all of its structural characteristics) and the visual media that we have available for representation (with all of their

structural characteristics as perceive.)

So, one of his central points is that the structural characteristics of the information and the visual media should be well-matched. For example, consider the question of different types of variables or dimensions. Bertin makes the same distinction that is familiar to psychologists as nominal vs. ordinal vs. metric scales. So, for example, Bertin suggests that colors are good for distinguishing among the different types of things on a nominal scale but not very good for representing an ordinal or metric scale because we do not usually perceive different colors as having a linear order. Similarly, he talks about such well-known (but often neglected) points as the need to represent different values in one's information with discriminably different perceptual values or the fact that the perceived magnitude of variables like area or brightness is not necessarily the same as their objective physical magnitude.

A second major way in which Bertin is insightful is in pointing to the importance of the question that you want to ask about the information in determining what will be an effective display. Some questions are easy to answer with given graphic displays, others are not.

(Here a set of slides were shown -- all graphs in which some comparison of values was intended. In most cases, it is difficult to make the comparison. In one, the

intended comparison is among the slopes of the slanted ends of a set of bars.)

The ease of answering the question depends upon the resources that our perceptual apparatus makes available.

As Steve Kosslyn put it in a recent review of several books on graphs and charts, "Graphics obtain their power because they tap into the very powerful (but at times eccentric) human visual information processing system," and the effectiveness of graphics has to be evaluated relative to the nature of the human information processing system.

Kosslyn acquired his special expertise about graphics working on a major project that I had something to do with initiating and that has led to the best unavailable treatment of graphic representation (see NIE final report). The project was designed to build upon Bertin's conceptual accomplishments and to be a comprehensive treatment. So, it began with the collection of a large sample of graphics from a wide variety of types of publications.

Kosslyn and Steve Pinker had the idea of approaching the problem with an essentially linguistic methodology. As a linguist tries to state grammatical rules that distinguish grammatical and ungrammatical sentences, they tried to state rules to distinguish graphics that are intuitively judged to be good are bad.

Since they are not yet easily available (but see the reference list for forthcoming publications; in addition,

there is a book manuscript that may sometime be published) I will quickly go through the principles they derived, explaining and illustrating some of them.

(Many of these principles were illustrated with slides of graphs and charts that are defective with respect to the principle in question.)

This conceptual framework for analyzing graphs and charts is taken from Kosslyn, Pinker, Simcox & Parkin (1983), the final report to NIE. The project produced a detailed questionnaire for analyzing graphics in these terms that is included in the final report. This framework is an extended analogy to the different aspects of linguistic theory.

There are syntactic principles applying to the physical characteristics of the graphic display itself:

*adequate discriminability

*perceptual distortion (respect perceived magnitudes)

*gestalt organization (e.g. do labels group well with the things they label)

* dimensional structure (matching the structure of dimensions as Bertin suggested. Also, don't use dimensions that integrate -- like the height and width of a rectangle -- to convey separate variables.)

*processing priorities (features that attract attention should be important, meaningful)

*processing limitations (don't give people more

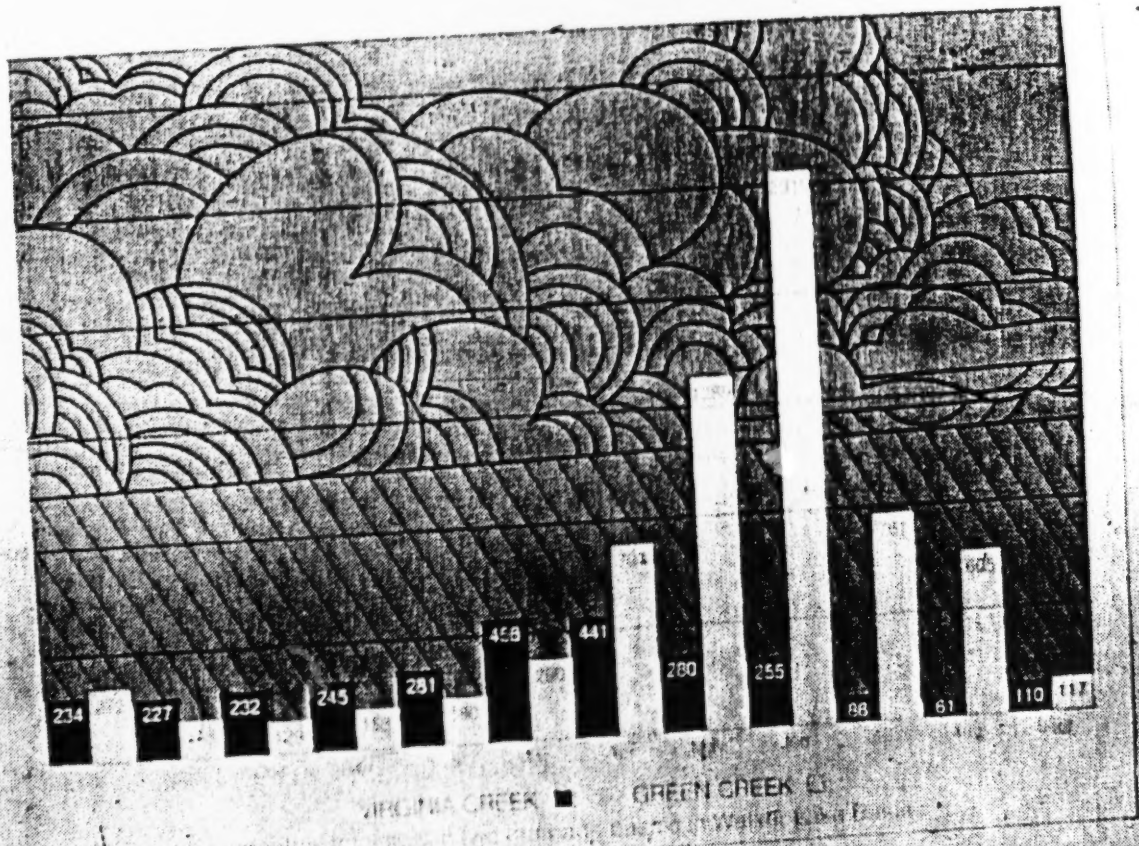


Figure 8.24 ... into which Virginia and Green Creeks drain.

Inappropriate Processing Priorities: Distracting Background

88

E Repeat Step D using masses of 400, 600, and 1,000 grams.

a Record the data in the appropriate place in your table.

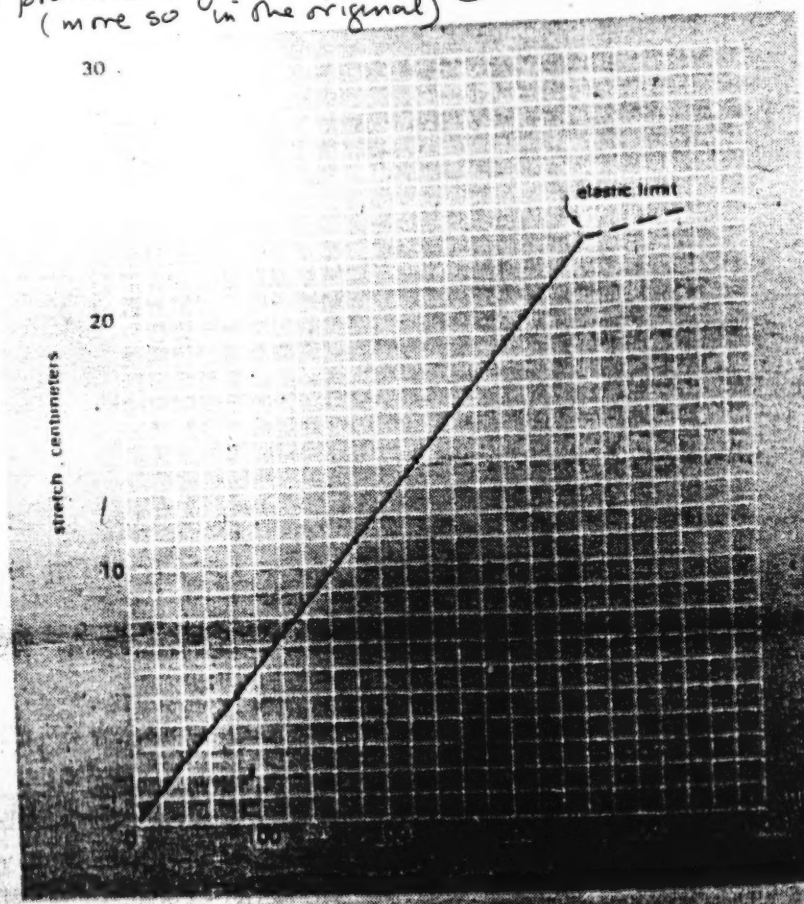
b Predict how many centimeters a 700-gram mass would stretch the spring.

F Check your prediction by attaching a 700-gram mass to the spring.

b How close was your prediction?

G Prepare a graph to show the results of your experiment with the spring. Since you chose the force units in advance, they become the independent variable. Plot the weight along the horizontal axis. Label the vertical axis *Stretch, centimeters*.

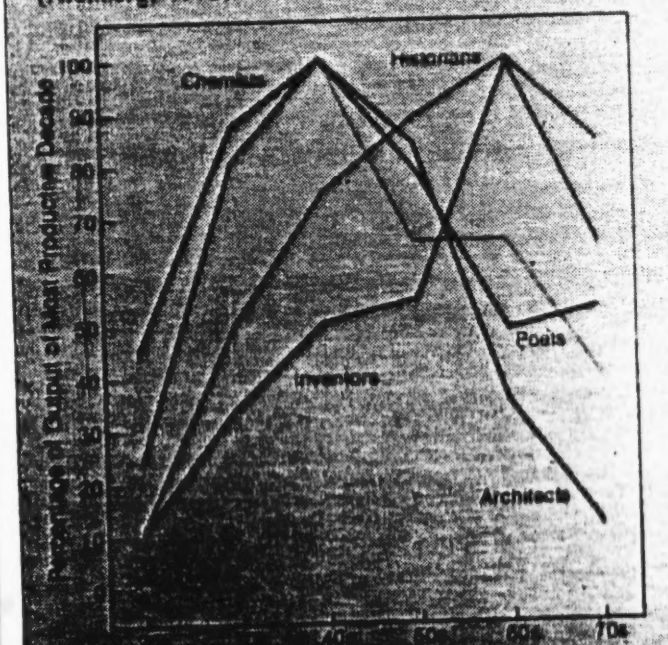
Overly prominent grid: processing priorities (more so in the original)



5-6 Sample graph illustrating the relationship between force applied to a spring and the distance the spring is stretched.

...or be due ...there is any ...functioning among peo... more marked ...Those individuals who ...in their younger years ...even more skilled. As in young ...of education that an individual ...his social class, his health, how active he is, and ...remaining in the current environment is are likely to be more important than age in determining ...how well or how poorly he functions intellectually ...(Baltes et al., 1973).

Despite the fact that many middle-aged people believe that their memory is not as good as it was and fear that they cannot learn new skills as easily as they used to, a person's ability to remember and to learn shows little decline in middle age. If middle-aged individuals are given as much time as they need to learn or remember, they are likely to do about as well as younger adults (Canestrari, 1963). Again, health, education, and individual differences make a difference. In addition, how motivated an individual is to learn or remember, how interesting or meaningful the information is, and how much recent educational experience he has had are likely to be more important than age in affecting learning and memory abilities (Arenberg, 1973).



...believe that a middle-aged person holds a ...point of view and resists change when the ...calls for it. This assumption appears to be ...ened by the finding that a person over fi... more likely to agree with clichés than your... and adolescents are (Riegel and Riegel, 19... ever, what appears to be a rigid approach ... solving is less likely to be due to a "... "cautious" attitude than to the way that th... aged adult's abilities have been affected b... experiences. For example, a middle-aged ... to solve problems and to think as well as ... adult, but his greater number of past associ... experiences may interfere with how flexibly ... problems. In addition, well-established wa... ing problems, which tend to look rigid in l... test situations, may serve individuals wh... confront the problems of everyday life.

The ability to be creative also does ... solely to youth. Adults in their middle year... equally creative. In fact, when creativity is ... in terms of total productivity rather than ... quality, creativity peaks at an older age. Fo... the decade of the forties is generally the mo... tive period of life in the humanities, science... (Dennis, 1966). Although an individual's ... ity in the arts declines somewhat during ... years, the productivity of persons work... sciences and humanities remains fairly s...

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Gestalt grouping problem: Which label goes with which line?

Figure 21.5 Graph showing productivity for certain professions, expressed as a percentage of the output of the most productive decade (designated as 100 percent). Poets, architects, and chemists usually achieve maximum professional productivity during their forties, whereas inventors and historians do so during their sixties. The data summarized here should be considered illustrative, because the subjects were not uniform in degree of eminence. Also, the units of productivity (for example, a sonnet versus a history of Rome) are not equivalent. (After Dennis, 1966).

COVER STORY

"It's Your Turn in the Sun"

Now 19 million, and growing fast, Hispanics are becoming a power

In Washington, D.C., leaders of 120 Spanish-speaking organizations call for a White House conference on Hispanic Americans. Among the demands they want aired: greater emphasis on bilingual education; bigger immigration quotas; more federal civil service jobs.

In Sacramento, California's Governor Jerry Brown drops in on a Mexican-American convention. "You're the leading minority in the Southwest," Brown tells the crowd. "It's your turn in the sun and I want to be part of it."

In Miami, Carlos Arboleya, president of the area's Barnett Banks (assets: $315 million), surveys the local Cuban-American community and confidently declares: "History will write Miami's future in Spanish and English."

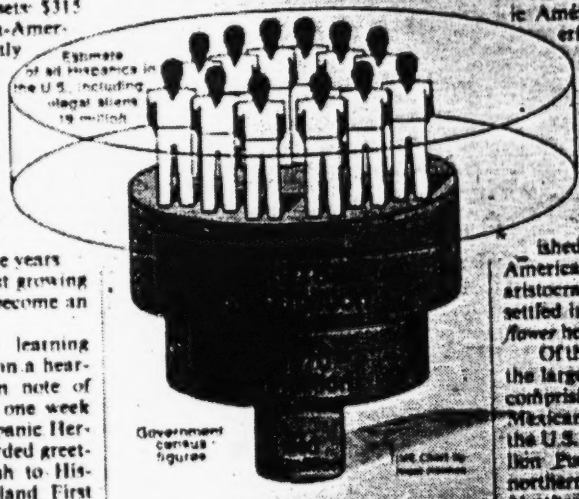
That extraordinary vessel, the American melting pot, is bubbling once again. The source of ferment: American residents of Spanish origin, whose official numbers have increased by 14.3% in the past five years alone. Now the country's fastest growing minority, they are bidding to become an increasingly influential one.

Hispanic Americans are learning how to organize and how to win a hearing. Jimmy Carter has taken note of these stirrings; he proclaimed one week last month to be National Hispanic Heritage Week and sent tape-recorded greetings in his unpolished Spanish to Hispanic communities across the land. First Lady Rosalynn Carter underlined those *saludos* by appearing at a Washington fund raiser for Congress's five-member Hispanic Caucus.

The Hispanic presence has been a palpable one in U.S. life for centuries. But broad awareness of its scope and potential did not really dawn until the 1960s with the unionizing struggles of Cesar Chavez's United Farm Workers and the spread of Hispanic populations. Today, migratory bands of Hispanics are picking apples in Washington and Oregon, helping with the harvest in the Midwest, tending vegetable and fruit crops in California's fertile valleys. Hispanics are also flooding virtually every important U.S. city in search of better jobs, creating Latino enclaves from the crowded *barrios* of East Los Angeles and Spanish Harlem to the manicured suburbs of Dade County, Fla.

They play an important role in shaping the nation's politics and policies. Just as black power was a reality of the 1960s, so the quest for Latino power may well become a political watchword of the decade ahead. Predicts Raul Yzaguirre, director of the National Council of La Raza (The Race), an umbrella group of Hispanic-American organizations: "The 1980s will be the decade of the Hispanics."

Statistics back up Yzaguirre's contention. According to 1978 census estimates, there are 12 million Hispanic Americans in the U.S. Hispanic leaders, however, claim that their constituency was seriously undercounted in the 1970 census and all subsequent projections. The spokesmen may have a point. Until 1960, census takers counted as Hispanic only people born in Spain, Mexico, Central and South America, the West Indies, Puerto Rico and Cuba, plus any U.S. residents with Spanish surnames. In the 1970 census, the definition was broadened to include the racial origin of respondents no matter the accident of birthplace, resulting in a dramatic increase in the numbers of Hispanics (*see chart*). Census officials have promised to take special pains to get a more accurate count during the 1980 census, in effect acknowledging that their methods have been inadequate.



Even the most reliable census figures, however, fail to take into account the enormous numbers of Hispanics who are living and working in the U.S. illegally. Because the birthrate among Hispanics is [illegible] higher than among blacks, and because Hispanic immigration (legal and illegal) is running at a staggering rate of an estimated 1 million people a year, Hispanics may overtake American blacks within the next decade. Already the two groups are competing fiercely for jobs and Government aid.

As blacks are united by race, Hispanic Americans are united by two powerful forces: their language and their strong adherence to Roman Catholicism. But many more factors divide them. They may be Castilian Spaniards or Caribbean islanders or Spanish-Indian mestizos. Among them are Cubans who fled to the U.S. with needed middle-class skills; impoverished Puerto Ricans or Mexican Americans looking for a job—any job; aristocratic Spaniards whose families settled in the Southwest before the *Mayflower* hove into Plymouth Harbor.

Of the officially recognized Hispanic groups, the largest single group is the Chicanos, comprising some 7.2 million persons of Mexican origin concentrated in the U.S. Southwest. An estimated 1.5 million Puerto Ricans live, chiefly in northern-central states, particularly the Northeast. Some 700,000 Cubans, many refugees from Fidel Castro's regime, now live in the U.S., mainly in New York and Florida. But there are also Dominicans, Ecuadorians, Colombians and many others. Latin American countries and Spain itself scattered all over the U.S., totaling an additional 2.4 million Hispanics.

The groups may [illegible] have little, [illegible] mobile Puerto Rican [illegible] little in common with [illegible] Cuban-American migrant [illegible] even the (impoverished) New York [illegible] and newly arrived Dominicans [illegible] both native Americans. Puerto Ricans [illegible] some of the Mexicans, [illegible] asserted (but believe [illegible]

[illegible]

Dimensional Structure

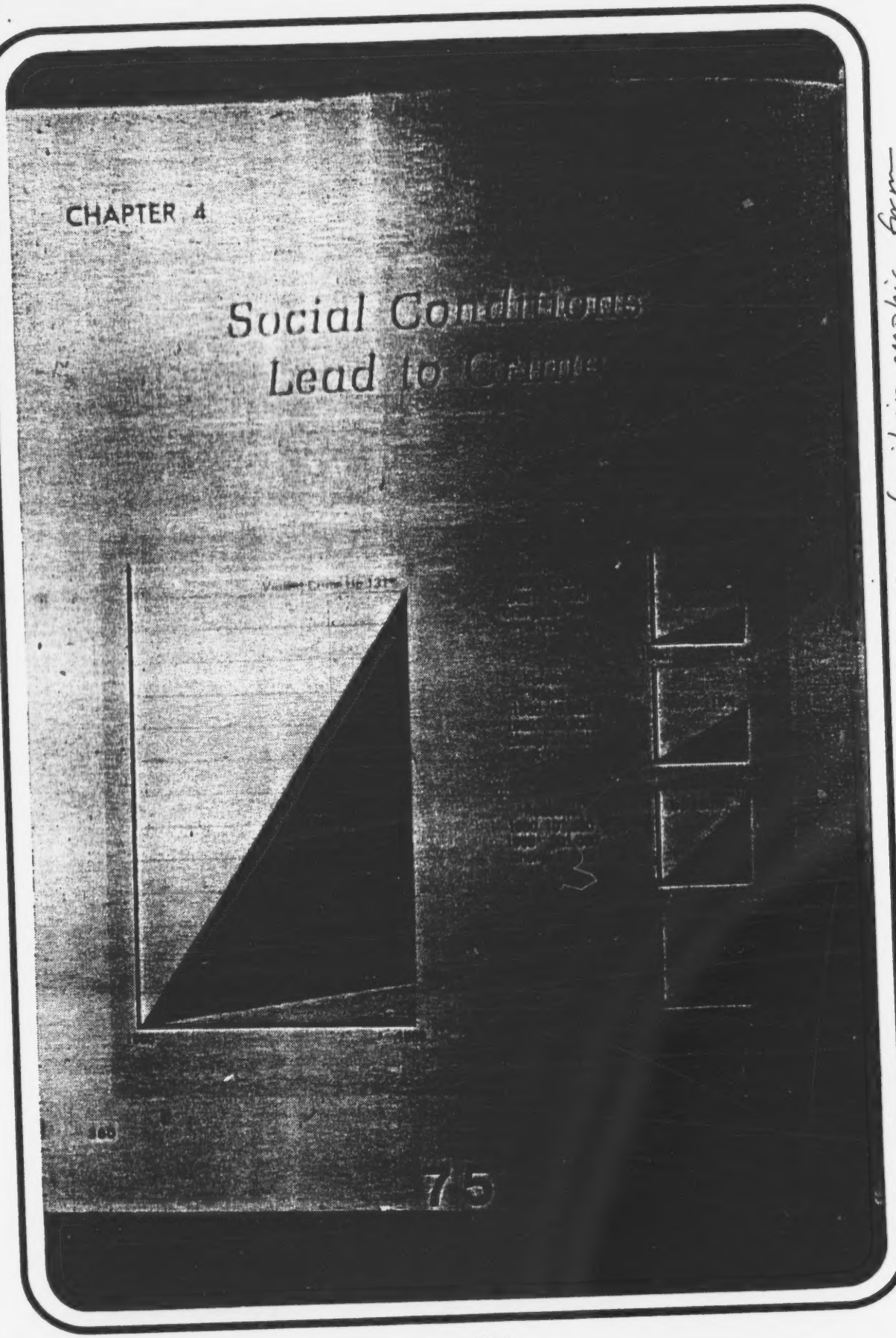
information than they can handle)

It may be worth noting that the author of a recent, popular book on graphics, Tufte, disagrees on some of these points. He favors cramming as much data as possible into a single graphic and states that physical variables such as area should be matched to the objective, not subjectively perceived, values. This disagreement may be related to the difference between Tufte's intuitions based on the personal use of graphics for professional data analysis and the consideration of graphics as effective communication devices. Tufte is extremely emphatic, however, about minimizing the amount of "non-data ink" -- the kinds of distracting grids and decorations that violate the "processing priorities" principle.

Semantic Principles

*surface compatibility (attend to typicality of symbols, semantic markedness in relation to the directionality of dimensions, cultural conventions of color interpretations, etc.)

*schema availability (conventional graphic forms are easier to process and enable people to deal with more information; unconventional graphic forms become problem solving situations)



Schema Availability: An unfamiliar graphic form + other problems.

Formal Principles

*internal mapping (e.g. there should be a good key)

*external mapping (meaningful differences in a variable correspond to available differences in physical marks; unambiguous interpretation)

Pragmatic Principles

*invited inferences (problems exist with truncated scales, varying scale types such as log vs. linear, 3-D perceptual effects)

*context (consistency with text or oral presentation)

Notice how much of the psychology we know -- from old psychophysical and Gestalt laws to more modern schema notions -- is relevant. And notice how much is relevant that we do not know about. Even the Gestalt laws have never been stated with a precision that would enable us to program them into an "expert system" for graphic production or even graphic evaluation.

In particular, there is a good deal that needs to be learned still about the issue of the questions that can be easily answered from a graphic display. Fundamentally, this has to do with the perceptual processing operations that are available to relate one part of a display to another.

The best clues to what these might be come from

Invited Inferences

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NATIONAL AFFAIRS

political instability in Iran and Iraq has created what Yamani calls a "psychological climate" of extreme nervousness over the supply outlook. Uncertain about how much oil they will be able to purchase tomorrow, oil companies, traders and speculators are buying all they can today—pushing up prices even further. Not even the prospect of a recession holds any promise of a break in prices. The oil exporters have learned to adjust their production to the ripples in world demand—and with spot prices soaring, they no longer need high-volume sales to produce big revenues. Unlike the last recession, which effectively [illegible] there. . . The chances of having gas lines next year are pretty high because the chances of something going wrong in the oil market are pretty high."

But over a period of years, the energy legislation now threading its way through Congress could encourage both conservation and domestic production. In broad outline, if not precise detail, Carter may well get most of what he wants. Price controls are ended, and last week the Senate Finance Committee finally approved a windfall-profits tax that would raise nearly $142 billion in revenue over the next decade. Under the Senate plan, about $70 billion would be used for energy subsidies for low-income families, $22 billion for energy tax credits and $15 billion for mass transit. The committee bill would have to be reconciled with a House-passed version raising $213 billion.

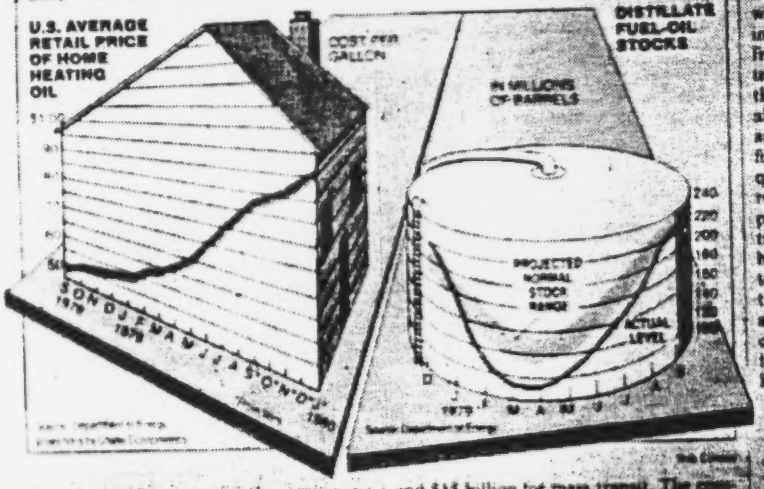
Congress is also close to giving [illegible] approval to an energy [illegible] that would provide [illegible] cedures to speed the development of alternative energy sources past regulatory roadblocks. And it seems likely to appropriate funds for a major synthetic-fuel program—though one with considerably less urgency and independence from Congress than Carter had originally proposed.

It will be 1990 before much synthetic fuel is produced, and energy conservation is also a long-term process. For the foreseeable future, the U.S. will have no choice but to continue to rely on imported oil—and that may well mean another oil crunch before next summer.

ALLAN J. MAYER with
JOHN WALLOTT, HENRY W. [illegible] and
WILLIAM J. COOK in Washington

AN EXPENSIVE WINTER AHEAD

There should be enough heating oil available this winter now that the industry has replenished the worrisome low stocks on hand last spring. But prices will be nearly twice as high as they were a year ago.



cut oil prices for two years, the coming one is likely to do no more than allow OPEC members the luxury of keeping more of their oil in the ground.

At the moment, the U.S. enjoys an adequate supply of fuel. Stocks of crude, home heating oil and gasoline are all higher than they were a year ago, and seem sufficient to get the nation through the winter without any major difficulty. But the higher prices will hurt. Experts reckon that just the oil-price hikes announced so far in 1979 will knock at least 1 per cent off real economic growth this year and next, while at the same time adding at least 1.5 per cent to the annual rate of inflation.

SHORT TODAY: In the short run, there's little anyone can do about prices or supply. "We're really on a knife edge," says president Robert W. Baldwin of Gulf Refining and Marketing Co. "All the factors that caused last summer's gas lines—limited supplies of crude, limited refinery capac-

THE MYSTERY OF MICHELE SINDONA

He reappeared as mysteriously as he vanished more than two months ago. One morning last week, Italian financier Michele Sindona telephoned his attorney from a New York City street corner. Associates found him 20 pounds underweight, with a bullet wound in his leg, telling a tale of abduction by left-wing Italian terrorists. "He was very agitated," said Dr. George Serban, a psychiatrist who was summoned by Sindona's friends. "He looked pale and haggard and wasn't talking very coherently." Sindona was taken to a hospital; where FBI agents and New York police tried to determine whether he had in fact been kidnapped or had merely fled to avoid prosecution for bank fraud.

Sindona is charged with illegally transferring $40 million from abroad to buy control of the Franklin National Bank and with embezzling $45 million from the bank, which collapsed in 1974. He is also accused in Italy of illegally removing $225 million from banks he controlled there. His U.S. trial was scheduled to begin Sept. 10. But on the night of Aug. 2, after being seen walking alone on New York's Fifth Avenue near his apartment at the posh Pierre Hotel, the financier vanished. His attorney subsequently said he received a letter from terrorists saying that Sindona was being held prisoner and would face "proletarian justice." As Serban tells it, Sindona said he had been forced into a car at gunpoint in midtown Manhattan, blindfolded, then shot in the leg while trying to escape about a month ago. More detailed information was hard to come by. "If we could only get him to say the house had running water—well, he hasn't even told us that much," sighed a law enforcement official.

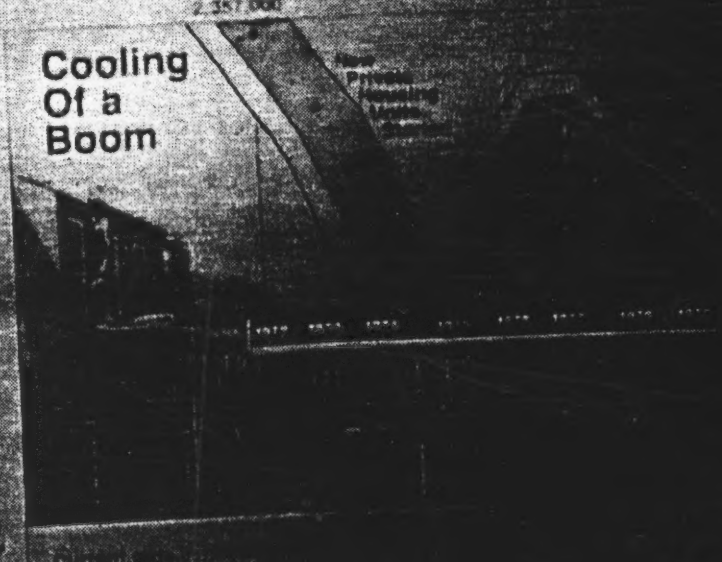
MAFIA: With so little to go on, investigators were perplexed. "I used to feel this whole thing was a hoax," said one New York police official. "Now, I'm not so sure." The kidnaping could have been faked just for nothing to gain by coming [illegible] Investigators theorize that [illegible] Mafia [illegible] by the [illegible] [illegible] [illegible] removed to have ties to the Mafia may have had a falling out with them.

The theory took on some credibility last week when Italian police arrested a Palermo man named Vincenzo Spatola, who was trying to deliver a letter said to be from Sindona to his Rome lawyers. Three days later, Sindona turned up in New York City. [illegible] [illegible] [illegible]

69

Hopeful Sign: No Crisis In Housing Market

High interest rates and high prices aren't scaring away buyers. Result: Home-building is holding up better than expected.



remembering Kosslyn's point that we are tapping into the powerful human system of visual perception, and from thinking about the primary functions which that system evolved to perform -- maintaining a consistent representation of the external perceived world as both the perceiving individual and some objects in the perceived world move about. The paper by Haber that I have cited contains a particularly elegant discussion of the functional accomplishments of human visual perception. Of course, the theoretical description of the mechanisms responsible for these accomplishments is as yet incomplete.

Researchers who have been interested in the perceived structure of static visual patterns (such as Steve Palmer and myself) have suggested that any structure that could be generated by the transformations of visual stimuli that occur as a result of motion in the 3-D world will be perceived. Kosslyn's theory of visual imagery also describes a repertoire of visual transformations.

If the message you want to convey conforms to one of these powerful processing mechanisms, then it will be easily perceived. Unfortunately, it may also happen that unintended messages will be perceived if they happen to engage these mechanisms -- the inappropriate 3-D interpretation of graphic displays is probably the most common example of such problems.

Visual Representation in Problem Solving

Today there is intense interest in using visual representations to externalize, communicate, and support problem-solving processes. The advance of computer technology and associated advances in areas like intelligent computer-assisted instruction is generating new enthusiasm for visual representations as a means of instructional communication, for use in decision-support systems, and so on.

Why is this? It is not JUST a technology-driven phenomenon.

There is a long anecdotal tradition dealing with the importance of visual imagery in scientific thinking and discovery. Roger Shepard's article, The Mental Image, details some of this and refers to other discussions. He alludes to the important role of mental imagery in Maxwell's formulation of the electromagnetic field equations. It is an incredible experience to read Maxwell's original papers because they talk about space (the ether) being filled with huge, complicated, endless arrays of cog wheels. (You don't see many scientific papers like this these days.) It was these that provided Maxwell with an intuitive sense of what was going on.

According to his own reports, Einstein also relied on imagery as the primary medium for his creative thinking.

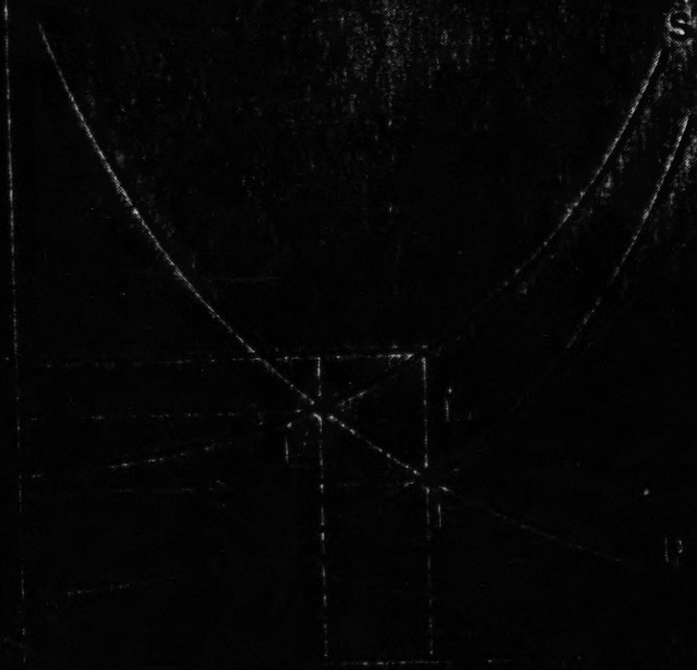
And there are many more examples.

The idea of being able to communicate such internal imagery experiences to students with computer graphics is attractive, as is the idea that computers might serve as cognitive prostheses for those who are not adept at such imagery. Computers can reduce the effort required for everyone and help to overcome the capacity limitations on imagery that everyone experiences. Computer graphics aids are now becoming widely used in chemistry, for example.

There are some conventional visual representations that are already in use -- like the free body diagrams used to solve mechanics problems in physics. Or supply and demand curves in economics.

(illustrative slides were shown)

In their article in the latest issue of Cognitive Science, Jill Larkin and Herb Simon try to provide some understanding of how and why such diagrams are useful and how, in detail, they are used in problem solving processes. Using computer simulations to explore the question, of course. The important point in their discussion is that the computational value of a representation depends upon both the data structure (perhaps a visual diagram, perhaps something else) AND the operations that are available to deal with that data structure. According to their analysis, much of the value of visual representations seems to come from relieving memory load and minimizing the need



Supply + Demand Curves

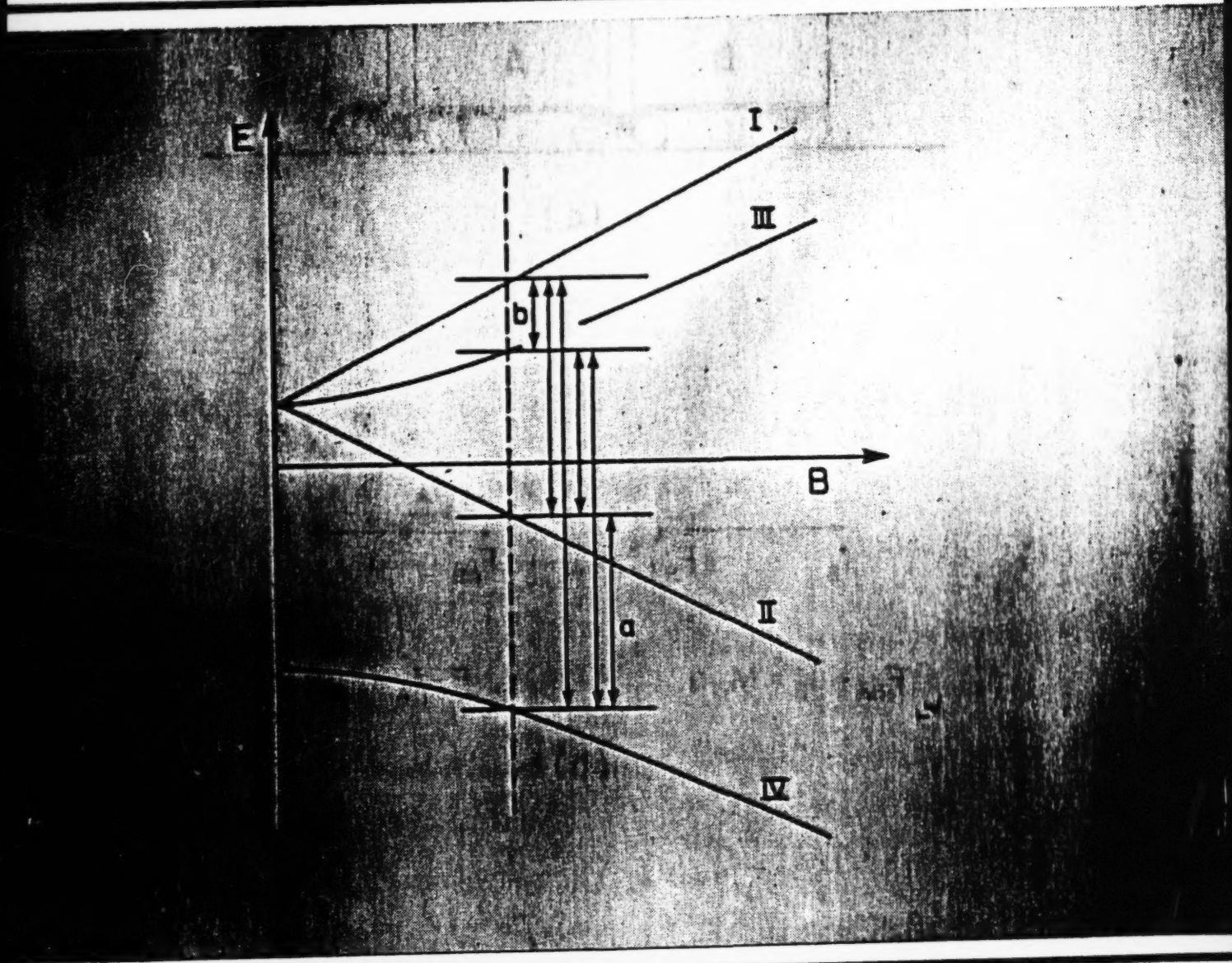
for search.

However, they remark that physics professors often complain that students won't use diagrams and "don't understand the utility of diagrams." That is because diagrams are not transparent devices. One must know how to translate from the problem situation to the diagram and back again. One must know what the things that one "sees" in the diagram mean in terms of the problem situation.

(a slide from Larkin and Simon of a rather unfamiliar diagram showing transitions among energy levels of the hydrogen atom was shown to illustrate this point)

Fred Reif has been devoting considerable effort to studying these translation processes for free-body diagrams and to figuring out how they can be taught. The magnitude of his effort should be fair warning that visual representations aren't panaceas. Their effective use must be learned.

But the big excitment today is creating novel visual representations to communicate (and support) cognitive structures and processes. Greeno, for example, has developed a representation for the semantic structures he believes to underlie successful solution of math word problems. There is some disagreement about the effectiveness or appropriateness of this representation: for one thing, it includes novel, non-transparent symbols that take some time to learn.



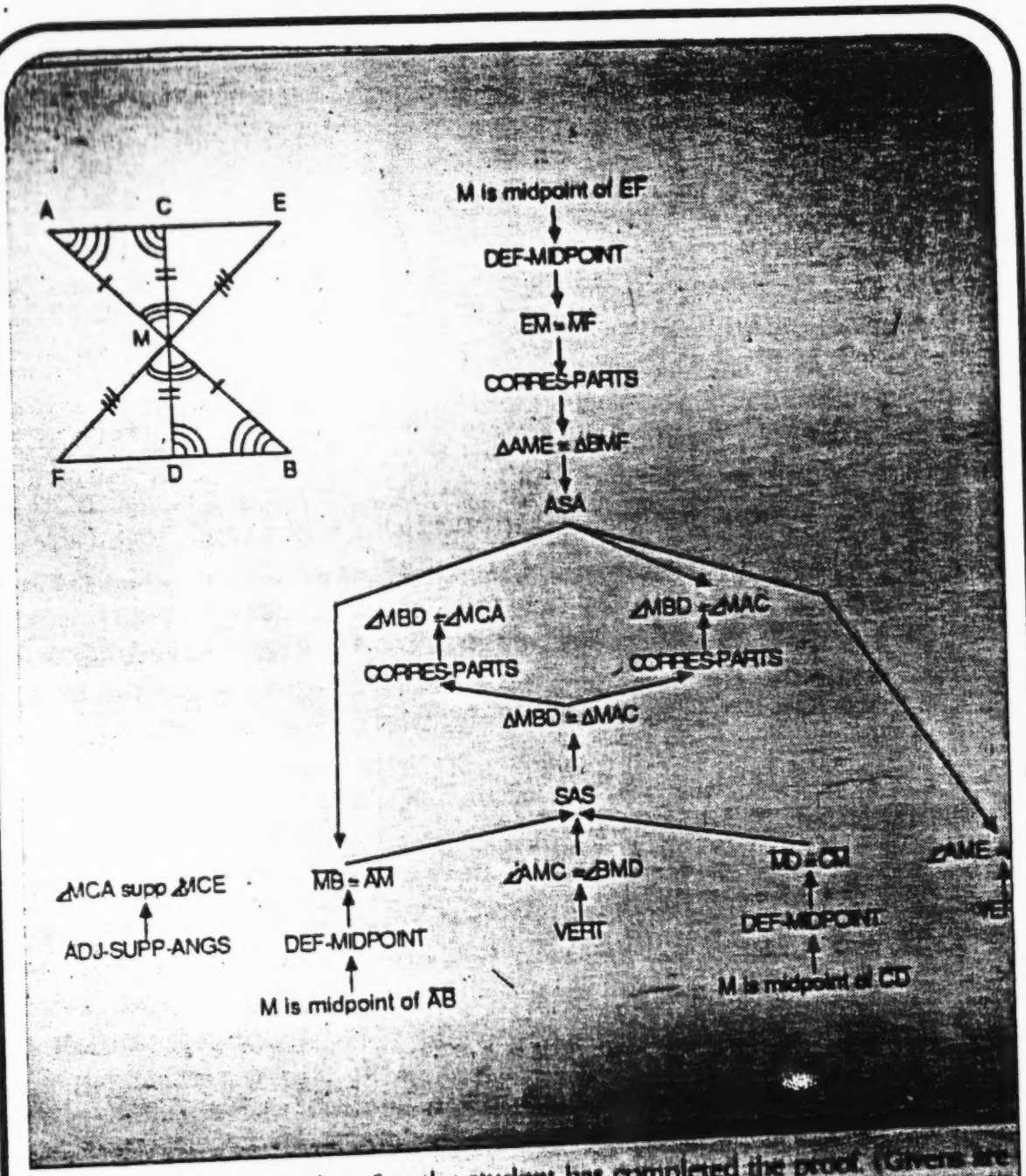
Atomic Energy Levels - hydrogen atom

John Anderson's intelligent geometry tutor incorporates a visual representation of the proof structure which seems very "right" to many of us, very "true" as a representation of the experience of searching for a path to link up mathematical statements.

And many more such representations seem to be in the works. But their creation is very intuitive and ad hoc. How can we understand what the alternatives are? Which would be best? How can we efficiently and deliberately design good representations in a principled way?

To answer these questions, I think that we can draw some lessons from the work on charts and graphs. Just as a graph is a mapping from the domain of information to the domain of visual displays, these new representations are mappings from internal cognitive structures to the visual structures of the display. Some abstract structural characteristics will be preserved in that mapping and others will not -- just as the structural characteristics of a variable in a graph may or may not be the same as theose of the visual dimension that we use to represent it. The visual representation may have excess baggage -- salient features that have no counterpart in the cognitive system we are trying to represent.

If we can be explicit about the fact that we are doing this mapping process -- focus on the abstract structural characteristics that we want to represent, then I think we



5. Geometry tutor display after the student has completed the proof. (Givens are bottom of the screen, the goal is stated at the top, and all points that appear coll diagram are assumed to be collinear. Adapted from Anderson, Boyle, and Reiser 1c.)

tch to repair the procedure (hence, e name *repair theory*). These repairs ow up as bugs on subsequent prob-

ples (Anderson 1985) are the

will be able to see what alternatives are available within the resources of visual media. We will be in a position to know what we are deleting and what we are adding in the visual representations. Then, scientific investigation of visual representations will be possible, not just the intuitive fiddling that is going on now.

The other lessons of the research on graphs and charts are important too. All the points about the perceptual characteristics of the display apply here too -- the importance of discriminability, of gestalt grouping effects, conformity of symbols to conventional expectations, the importance of the relationships among display elements that are salient and easily perceived, and so on.

In fact, I would argue that all of these display characteristics are much MORE important in such didactic displays. Because in them, the perceptual units and the perceptual relationships are to be used as templates and guides for the formation of internal conceptual structures. So mismatches and excess baggage become a much more serious issue than they are for graphs and charts that present information about concepts usually well understood by the readers.

It is, of course, a very fundamental question whether visual representations can in fact serve the conceptual scaffolding function that is now being attributed to them.

I think we assume they can. But do we know? Vygotsky suggested that unknown words tell the child there is a concept to be learned. The perceptual units in a visual representation may work the same way -- but we had better be careful that we get them right.

Conclusions

What I have been saying is that the effort to understand how visual media can be effectively used in educational communication returns us to the most basic and general questions about how visual information is coded and processed. Virtually everything that we have learned in the whole history of research on vision is relevant to our understanding of effective visual representations. Some of the gaps in our knowledge are made more evident when we analyze this problem. As yet, for example, we do not have much to say about the kinds of visual comparison processes or perceptions of relationships that are involved in using graphs to answer questions about the information they represent.

But for me, at least, and I hope for you too, a kind of deep unity is emerging in what had been some very disparate areas of investigation -- abstract pattern perception, graph reading, imagery, spatial ability -- a unity that arises from the common involvement of a perceptual system that evolved to serve particular functions. Hypothetical though it may be, this source of unity can guide us in more

systematic and fruitful investigations than we have seen in the past.

The same technology which now piques our interest in the educational potential of visual representations provides the tools we need to tackle fundamental questions about the nature of visual knowledge.

If anyone hoped that visual media are panaceas that overcome all problems of comprehension, I hope that I have given enough examples of the need for learning to interpret visual representations.

Graphs are not transparently obvious communication devices. (see Vernon and many of the illustrations of this talk)

Scientific diagrams can take a lot of learning to use.

Wherever we have known enough to ask the question, the role of learning or development in perceiving and comprehending visual media has appeared:

-- in Susan Carey's studies of human face encoding and recognition

-- in my own investigations of sensitivity to symmetries and other forms of structure in abstract patterns

-- in investigations of the perception of realistic visual scenes.

Visual knowledge builds upon a very powerful

perceptual apparatus, but it is knowledge nevertheless, continuing to grow and develop throughout life.

April 20, 1987

Visual Knowledge
SUSAN F. CHIPMAN
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